The Role of Renormalization Group in Fundamental Theoretical Physics[a]

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1. Introduction (Logic of science)

Here, I would like to discuss some general aspects of the logical structure of modern fundamental science and, in particular, the place and role of renormalization group (RG) in it. Here, by RG we mean the Stueckelberg–Bogoliubov formulation of the Renormalization Group, that is a one-parameter continuous group in a usual mathematical sense.

The importance of symmetries and groups in fundamental theoretical physics have been realized by some of the leading theorists more than half a century ago. One of its most prominent advocates, Eugene Wigner, proposed a hierarchical scheme establishing a relation between three categories: "symmetry or invariance principles", "laws of nature" and "events".

As he wrote in 1964 (see pp. 38 and 30 in Ref. [1]) :

> "What I would like to discuss instead is the general role of symmetry and invariance principles in physics, both modern and classical. More precisely, I would like to discuss the relation between three categories which play a fundamental role in all natural sciences: events, which are the raw material for the second category, the laws of nature, and symmetry principles for which I would like to support the thesis that the laws of nature form the raw material."
>
> "... the progression from events to laws of nature, and from laws of nature to symmetry or invariance principles, is what I meant by the heirarchy of our knowledge of the world around us."

Physical $\boxed{\text{EVENTS}}$ $\Rightarrow$ $\boxed{\text{LAWS}}$ of Nature $\Rightarrow$ $\boxed{\text{PRINCIPLES}}$ of Symmetry

Figure 1: **WIGNER Hierarchy**: *Events form the basis for laws. Laws provide the raw material for principles.*

This hierarchy follows the line of "science construction", of extracting regularities from observation, regularities (laws and principles) that form the skeleton of physical science.

However, principles and laws obey predictive ability. To follow the inner logic of science one should proceed in the opposite direction. Again, according to Wigner (p. 17 in Ref. [1]):

> "... the function of the invariance principles to provide a structure or coherence to the laws of nature just as the laws of nature provide a structure and coherence to the set of events."

This quotation with some details added can be visualized in the form of a scheme (see Ref. [2]):

[a] The text of the talk presented at the Conference "RG-96" (Dubna, Aug 96). To appear at the proceedings.

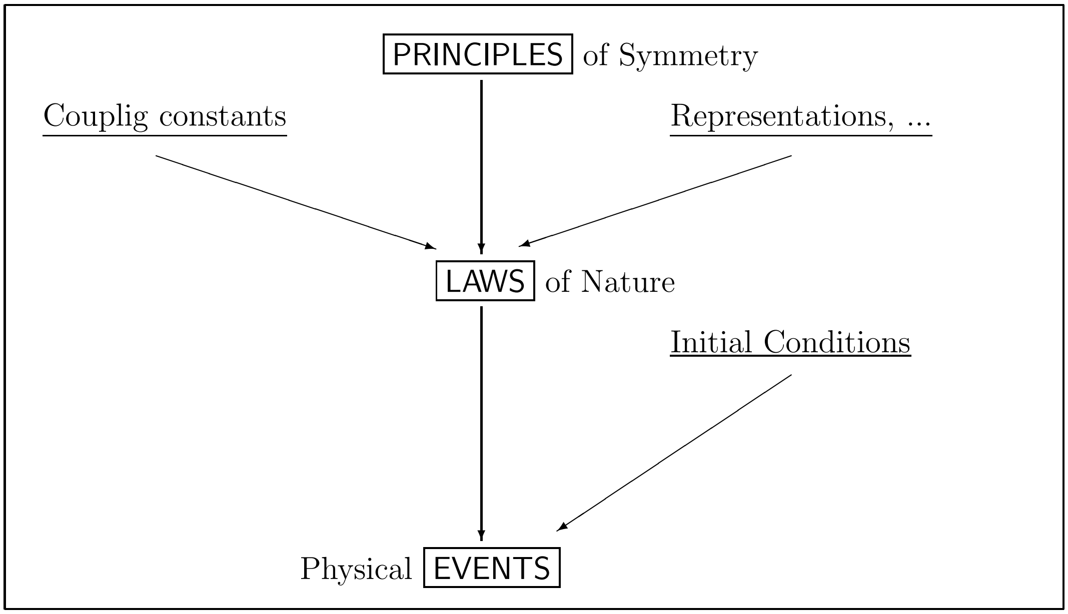

Figure 2: **Logic of science by E. Wigner:** *Principles provide a structure to the laws of nature. Laws define the Events pursuit.*

In what follows, we would like to discuss the validity of the Wigner scheme in modern physical science and indicate the place of RG in it. However, for this purpose, the scheme, Fig.2, is a bit sketchy. We have to modify it. Our first comment relates to the category of 'principles'.

2. Comment on "Principles"

Wigner paid attention mainly to principles of symmetry, like space-time (Poincaré Invariance, P, T) and internal symmetries (Isospin → Flavours, Colour). Meanwhile, in fundamental physics we deal also with some other principles, General Principles, like:

– Principle of QUANTUM PRIORITY which states that "quantum level of nature is the basic one and classical physics is secondary, being the limiting case of a quantum picture";

– Principle of UNITARITY that reflects the "conservation of probability" ;

– Principle of CAUSALITY: "Future cannot influence the past" (related to the mistery of a 'Time arrow');

– Principle of RENORMALIZABILITY [b] that acts as a selection rule for QFT models and can be formulated [3,4] as follows : "The given model of field interaction should be realizable on the quantum level". In combination with the principle of quantum priority this means that the renormalizability property should be considered as a nessesary condition for a given QFT model to have a chance to describe the Nature: i.e., RENORMALIZABILITY = RELIABILITY.

– The GAUGE DYNAMICS Principle [c] stating that the form of a dynamics, of a field interaction, should be deduced from a symmetry (by its "localizing").

[b] This needs quantum notions to be formulated in detail.
[c] This needs quantum notions to be motivated.

3. Are "Equations" equivalent to "Laws"?

The second comment relates to the Wigner's category "laws of nature". In our opinion they, generally, should not be identified with *Dynamical Equations* deductible from some basic Principles. Rather, these "Laws" are to be related to *Solutions* of Dynamical Eqs. To illustrate, consider the case of the Standard Model (SM) in QFT.

The most fashionable current topics in SM (Grand Unification, SuSy generalization, quantum gravity,...) are related to 'extremely high energy region'. However, there are two issues lying in the experimentally studied domain. These are: "Confinement in QCD" and "Vector boson masses in the ElectroWeak Theory":

– All experts agree that we have correct QCD equations responsible for strong interaction. However, the confinement phenomenon, being an essentially nonlinear quantum effect, still is not understood.

– The origin of gauge $W^{\pm}$ and Z^0 boson masses is "explained" by the so-called 'Higgs mechanism'. It is highly artificial and, technically, is based upon a very specific scalar field with imaginary mass and quartic self-interaction. (This mechanism also predicts particles which have not been observed yet.) The scalar field introduction destroys the whole beauty of the Gauge Dynamics principle. Meanwhile, there are serious reasons [5] to believe that spontaneos symmetry breaking of gauge symmetry can be treated as an intrinsic feature of non-Abilean quantum gluon field, as a nonlinear quantum phenomenon.

Both issues are related to common non-linear quantum topic –

Structure of the ground state of non-Abelian Quantum Field.

Here, we have beautiful equations, like the QCD ones, whose structure is determined by principles. However, we are unable to extract from them the very basic feature of strong interaction (confinement of coloured objects) and some other important information related to experiment. Instead, for the latter purpose we have to be satisfied with effective semi-phenomenological model constructions, like "MIT bag","Dubna bag", "low-energy chiral model" which are not directly related to general and symmetry principles. This means that "Equations", in practice, do not define the essential features of a system. It is improper to treat them as "Laws".

Another illustration is provided by the history of superconductivity. This phenomenon stayed unsolved by theorists for about 45 years. In the course of the first 15 years there was no adequate theoretical basement (of quantum mechanics = QM). However, during subsequent three decades we had general belief that superconductivity had to be understood as a macroscopical QM effect, but not understanding of this phenomenon on the basis of QM description of electron gas in metal. Instead, we used to content ourselves with semi-phenomelogical constructions like that of Londons and Ginzburg–Landau. Just they appeared as *"laws ... providing a structure to the set of events"*.[6] The situation is pictured on Fig.3.

1911	→	15 *years*	→	1926/7	→→	**30 years!**	→→	1956/7
Experiment Discovery				"Theory" QM Eqs.				"Laws"= Solution

Figure 3: *History of superconductivity (Difference between "Equations" and "Laws").*

Thus, we arrive at the conclusion that "Laws" should be substituted by two notions :

– Equations that can be deduced from Principles;

– Solutions of equations that are equivalent to "Laws" in a sense that they determine the physical system behaviour. In short –

Between "Principles" and "Laws" there should stand "Equations".

This means that principles provide the structure and coherence just to dynamical equations which, in a sense, could be treated as laws of nature formulated in a general form. However, as a rule, in modern science they have no close relation to events. These are rather solutions to equations which provide structure and coherence to sets of physical events. Instead of the Wigner-like scheme, Fig.2, we get:

4. "Logic of Modern Science" Scheme

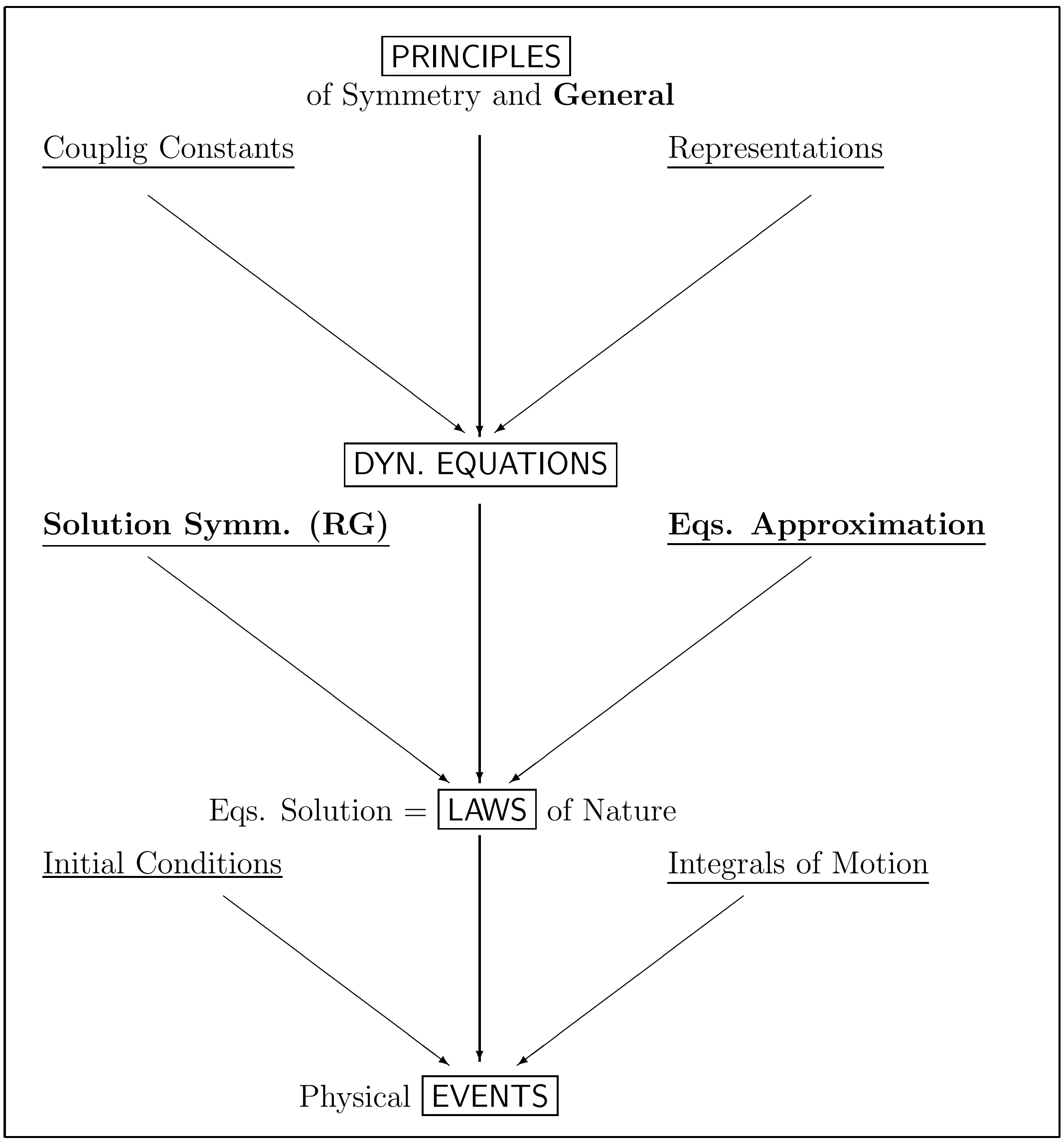

Figure 4: **The Logic of Modern Science:** *General and Symmetry Principles provide a structure to Dynamic Equations. Solution to Eqs. give the Laws.*

5. Reductionism vs Constuctivism

We believe that this modification has a direct relation to the debate between reductionists and constructivists. Two different credos have been formulated by Einstein (see, e.g. in Ref.[7])

EINSTEIN reductionism

"The supereme test of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction. (1918)

"...we would like not only to know how nature is organized (and how natural phenomena proceed), but possibly to achieve the goal which may be considered as utopian and daring – understand why nature is just the way it is". (1929)

and P. Anderson[8]

Modern constructivism

"The ability to reduce everything to simple fundamental laws does not imply to start from these laws and reconstruct the Universe"

"...the more the elementary-particle physicists tell us about the nature of the fundamental laws, the less relevance they seem to have to the very real problems of the rest of science..."

In our opinion, the real origin of constuctivists' scepticism is just the gap between "fundamental laws", that is implementation of Principles in the form of "Equations" (like Newton's, Maxwell's and QCD equations) and "Laws of Nature" that is solution to the equations (like Kepler's, Ohm's, Meissner's and Confinement Laws). The RG plays an important role in this gap filling.

6. Renormalization Group – Solution Symmetry

Renormalization group first discovered in QFT by Stueckelberg and Petermann was explicitly formulated by Bogoliubov and the present author[9] as an exact[10] group of transformations related to finite Dyson's transformations. Later on, it has been shown[11] that this exact group (which we call[12] the Bogoliubov Renorm-Group) is related to the symmetry of a given solution and consists of specific transformations of a scale and solution parameter(s) (that could involve, e.g., boundary condition parameters, like experimentally measured coupling constants); in a particular case this symmetry can be reduced to power self-similarity symmetry well known in mathematical physics.

The Renormalization Group Method(RGM) devised in Refs.[9] (see also English publications[13]) allows one to improve an approximate solution behaviour in the vicinity of a singularity by restoring the correct structure of this singularity.

As it is well known, the RGM proved to be an indispensable tool for analysing solution property of complicated nonlinear problems in : QFT (Ghost problem in QED; asymptotic freedom in QCD; Standard Model and Grand Unification), critical phenomena and phase transitions, percolation, turbulence, polymer theory and many others (including boundary value problems of mathematical physics[14].

In this context, we conclude that RG Symmetry being the property of a solution forms the basis for "filling a gap between equation and its explicit solution", solution that is necessary for the 'physical law' obtaining.

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